Digital Mechanics and The Rolling Coin Clock

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Abstract

Several ideas that always occupied me culminated in my design of a Digital Rolling Coin Clock. The proliferation of laser cutters has revived my interest in these ideas.

Sources of Inspirations. Clocks are fascinating mechanisms. I am especially attracted to those that display some curiosity feature. A few examples are shown in Figure 1: A ball rolls down a zig-zag path on an inclined plane in exactly one minute, hits a release mechanism that lets the plane tilt over, causing the ball to reverse its journey and the minute hand to move forward one step. Or a ball hanging from a string on a

Figure 1: *Curiosity clocks: Inclined plane clock, flying pendulum clock and Jens Olsen's astronomical clock at Copenhagen town hall.*

swinging arm is delayed by its interaction with two poles that you would recognize if you ever played pole tennis. I remember making detours to watch the shop window where this clock was displayed at the Royal Hotel in Copenhagen.

Those were also the days when computers were new and rare, huge and expensive, rather inaccessible and, most of all, exciting. I became interested in understanding their inner workings. I wanted to find ways to illustrate their binary operations by means of mechanical analogues.

Experiments with Water. One early attempt was inspired by the nodding bamboo contraptions that you see in Japanese gardens. As it fills up with water its balance is shifted until it tips over and spills the water into a basin. The sound it makes as it falls back is supposed to keep deer away from your vegetables. I saw it as a mechanism for counting portions of water. Too bad, it could only count to one. I found a way to improve this: You can make a "binary pitcher" out of a similar bamboo rod, pivoted just below a partition wall and cut at a low angle slanting away from that wall on both sides (Figure 2, right). This will have two stabile states instead of just one, and two "output gates". I chose to use milk cartons that I cut up and folded into binary pitchers and funnels to direct the output from each binary pitcher into two others at the level below.
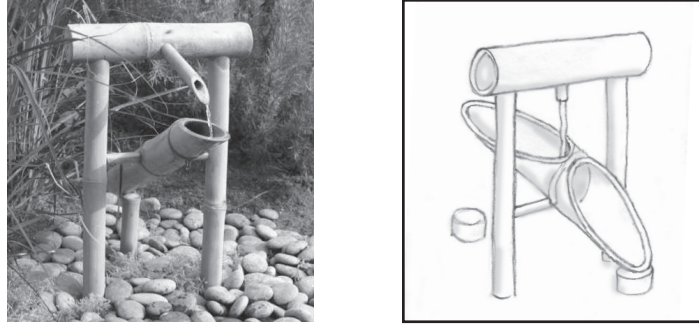
Figure 2: *Traditional Japanese deer chaser (left), my two state version (right).*

This was all suspended on a scaffold of dowels. At the bottom level I had placed a row of binary indicators: Each of them an assembly of three chambers, one of which was closed with a portion of water to stabilize the unit in the vertical position, the other two were closed at the middle and open in either end (top and bottom). When water pours into the top chamber it causes the module to flip over and pour out the water again.

At this time the LED seven segment displays had been introduced and became popular as digital displays in pocket calculators and other instruments. I admired their extreme simplicity, and wanted to construct a similar display using my flip over water modules. I sketched a solution, but never tried to build it.
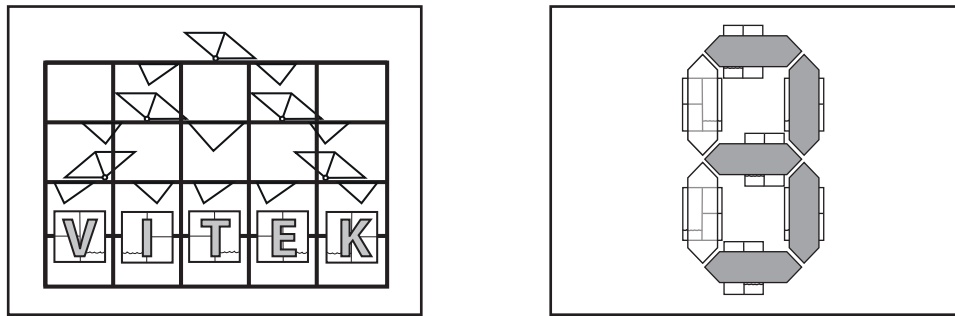

Figure 3: *Sketches of the tv setup, drawn from memory (left) and a seven segment display unit (right)*

However, a guy from TV had heard of what I was doing and asked me if I could build my digital water clock and show it in an educational science program about time that they were preparing. I wasn't quite ready for that, but we ended up building an acrylic version of my experimental set-up. It had the title of the program written on the flip-over modules at the bottom. During the introduction to the program you saw the title getting more and more scrambled as the modules started flipping over in a seemingly random order, and of course at the end of the program all modules miraculously returned to their original state.

From Rolling Balls to Rolling Coins. Another obvious candidate for digital mechanics is the rolling ball track. At a science center in Eindhoven, NL, I was fascinated by a huge rolling ball construction with clever switches, loops, and mid-air collisions. Even more inspiring was an educational device (also made for TV): A triangular board covered with plexiglass and with grooves for the balls cut like an inverted binary tree, so that a ball entered at the top apex could end up at one of eight different exits at the bottom. At each node was a metal slab that worked as a switch activated by the passing ball, so that the next ball would choose the other outgoing path. However this switch could also be activated externally by turning a small plastic disk, mounted on its axis above the plexiglass cover. These disks had narrow slots at suitable intervals around their edges, so that you could connect any two disks with a string squeezed into the appropriate slots, creating a feed back mechanism. Thus you could program this simple toy to simulate various logic gates – fascinating!

With my digital water clock in mind, I now wondered how to build a rolling ball digital clock? I could use the logical elements from this educational toy. What I missed was a flip-over element that I could use to

construct a display unit. I remember visualizing the element I used in my water project operating with balls instead of water. I didn't like the idea. A ball inside a closed chamber would make unwanted noises and the incoming ball would escape at the bottom in a rather uncontrolled manner.

The idea of using coins instead of balls came out of nowhere. I liked it because it helped me solve the problems I had with the ball track, and because I had never seen it done before – I still haven't! Let us go back for a minute to the problem I had with the balls. I knew I needed a ball in the lower part to stabilize. I would have a ball arriving at the top, causing the balance to shift and the module to flip over. How could I catch the escaping ball? Would I need a funnel for that? That did not seem compatible with the idea to combine more of these elements into a compact seven segment display. But what if the stabilizing ball was also the ball to escape at the bottom as the incoming ball rolled in at the top? That would make the trapped ball superfluous, which was a good thing. All I needed was a simple mechanism that could push out the stabilizing ball as the next ball rolled in at the top. I think this might have been where my unconscious brought in the coins.

Developing Rolling Coin Mechanisms. Coins roll elegantly on a slanting strip mounted on a nearly but not quite vertical back plate. Construction gets simplified compared to building tracks in midair, but of course the limitation to a two-dimensional surface (or its close proximity) also presents some interesting challenges. The flip-flop needs three layers, as the back becomes front when it flips over. The middle layer has cavities for the stabilizing coin and the coin rolling in at the top. The push out mechanism is simply a straight bar pivoted at the center. The module needs to be properly aligned with the back plate. If not stopped the flipping module would keep swinging like a pendulum for a while. A latch at the top takes care of this, allowing it to pass on its first swing, but catching it on its return. I'm sure a similar device could be achieved with rolling balls, but it would be a lot more complicated to construct.

I built and tested this module and it worked perfectly (Figure 4, left). I had already tested a simple binary switch that I would use to count 64 half-swings of the pendulum. It looks like a tilted letter **y**. Let us consider three of them in a row as in Figure 4, center. The first coin will roll into the "mouth" of the first **y**
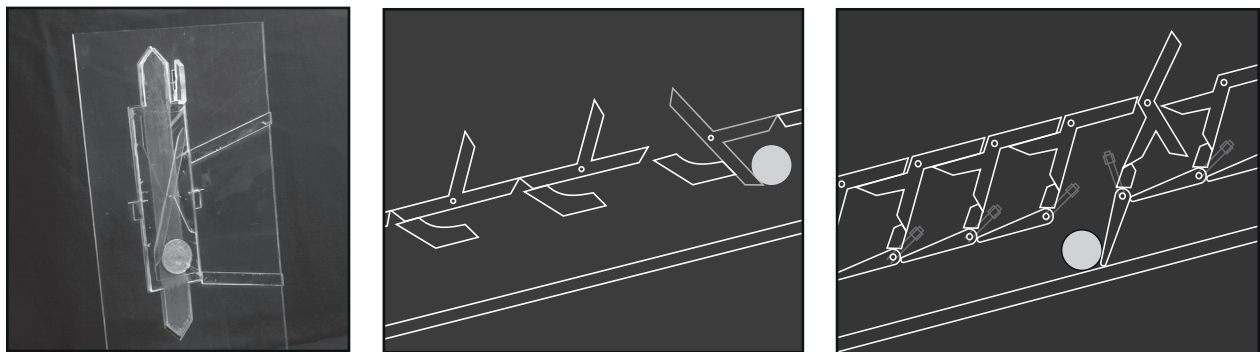

Figure 4: *Test module for flipover unit (left), binary switches (center), and serial switches (right)*

and drop down, tilting the switch to its alternate state. Every second coin will drop down here. The second coin will roll over the top of the first **y** forcing down its long stroke and returning it to its original state, then into the "mouth" of the second **y** where it drops down. Every fourth coin will drop down here. The eighth coin will roll over all three switches and return them to their initial state and everything can start over.

To control the four digits of the clock I need a mechanism that can count in bases other than two. For this purpose I have created a row of identical switches that open one at a time (Figure 4, right). When a coin drops into the open switch it closes and the next one opens. After the last switch has closed the coin will roll over all of them and open the first one.

The Rolling Coin Clock. I have tested all of these elements, some more thoroughly than others. I have also tested a stepwise escalator to return the used coins to a queue at the top, and a gravity escapement to let the waiting coins through in step with the swinging pendulum, at the same time each coin, in virtue of its weight, delivers a small impulse to the pendulum, keeping it in motion. In Figure 5 I have sketched my vision of the complete clock. Between the display (left) and the step escalator (right) is the control section with the pendulum behind. At the top, below the gravity escapement, is an and-gate causing exceptional action when digit one is 2 and digit two is 3. Immediately left of this are the binary counters that let every 64th coin flip down to four rows of sequential switches – one row for each digit. Under each individual switch is an activator connected with strings to switches in the corresponding digit, determining which flip-flops to be activated next. Some special features have not yet been tested. Nor have I, until recently, tested how well the various parts work together. In spite of this, I never doubted that this clock could be built and made to work, and that it would be just as spectacular as I had imagined it. On the other hand I knew it would be an enormous effort if these thousands of parts all had to be accurately hand cut; and the thought of discovering that some adjustments were needed, that could mean starting all over again, made me hesitate. Now laser cutting has completely changed that situation, and I have decided that the time has come to do something about it. After all, coins might not be part of our daily lives in a not too distant future. The work I hope to be showing at this year's exhibition is meant to demonstrate some of the essential elements.
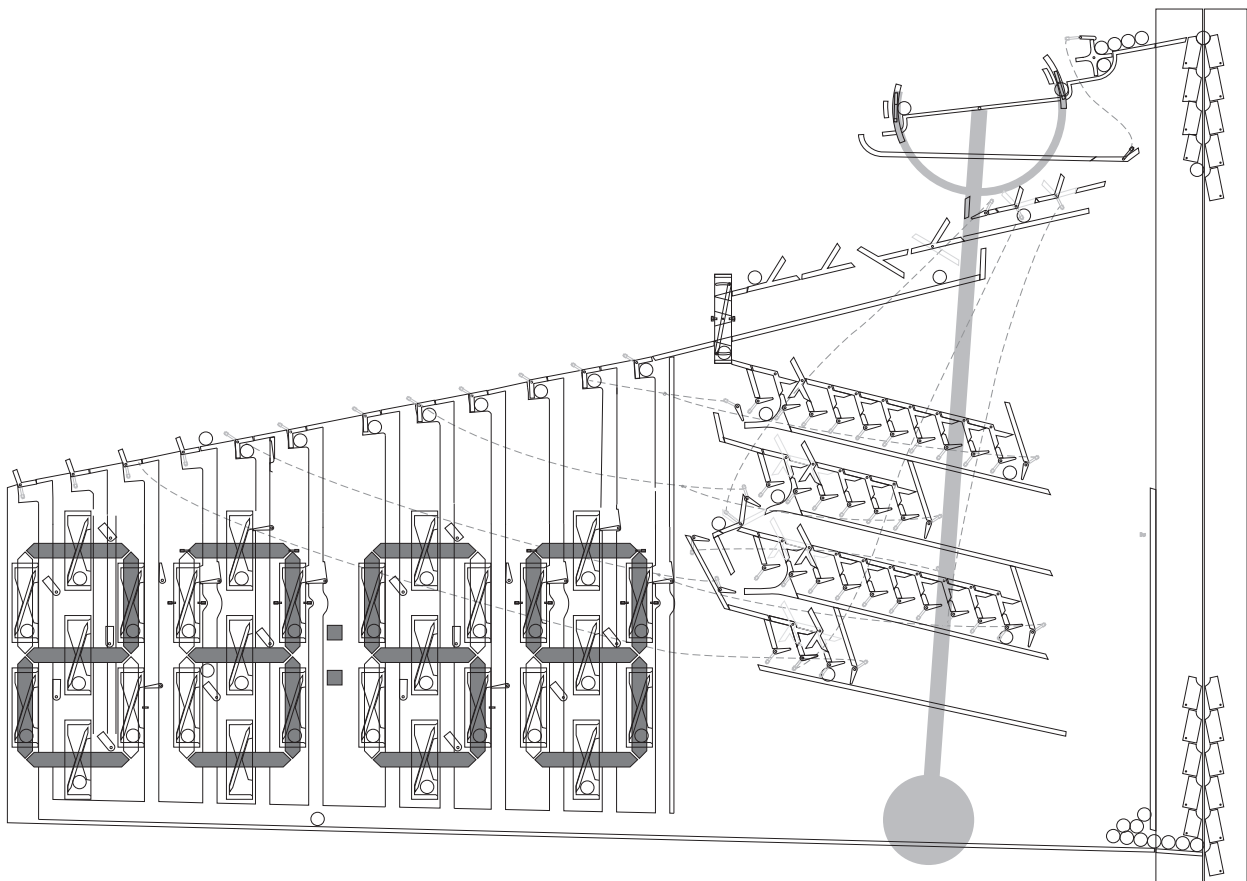

Figure 5: *A preliminary layout for the digital rolling coin clock.*